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Dr. George S. Sperling

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University of California - Irvine
Office of Research Administration
115 Administration Building
Irvine, CA 92697

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13. ABSTRACT (Maximum 200 words)

This grant was used to support the graduate education of Erik Blaser, who is currently in his fifth year of graduate study for a Ph.D. degree in the Department of Cognitive Science, University of California, Irvine. Blaser's formal course work proceeded normally throughout with very high grades (A or Satisfactory in all his courses). Blaser failed to finish in a par four years, and is now in his fifth year, currently supported as a teaching assistant, and concentrating fully on completing his thesis research. His thesis project is a method of measuring the modulation transfer function of spatial visual attention. When the assumptions of his method of measuring attention are satisfied, the method enables one to calculate, for any attentional demand whatsoever, the extent to which an observer could mould his or her distribution of spatial attention to meet the demand. This research is being reported at ARVO, 1997, and a preliminary report is attached herewith.

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Erik | A. | Blaser

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Cognitive Science | eblaser@aris.ss.uci.e

DEPARTMENT | E-MAIL ADDRESS

University of California, Irvine

INSTITUTION

STREET ADDRESS

Irvine, CA | 92697

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Measuring the Spatial Resolution of Visual Attention.

((*Erik Blaser**, *George Sperling**, *Zhong-Lin Lu*†)) *University of California, Irvine CA 92697, †University of Southern California, Los Angeles, CA 90089.

Purpose. To derive the spatial modulation transfer function and thereby the effective receptive field for visual spatial attention. **Procedure.** Lu and Sperling[1] recently identified a class of motion stimuli which is ambiguous to first- and second-order motion systems. However, a third-order motion system, which relies on visual attention to select certain features and bind them together across frames, yields a clear perception of motion. We extended their paradigm to stimuli consisting of temporal sequences of five windowed horizontal sine wave gratings. Each grating was exposed for 100 msec then displaced 90 deg consistently to the right or left relative to its predecessor (left/right direction was randomized between trials). Approximately isoluminant gratings (alternating bands of red and green) alternated with second-order gratings (alternating bands of high and low contrast texture). No motion is perceived in such stimuli unless attention is allocated appropriately. Subjects made direction-of-motion judgments under "attend to red" or "attend to green" instructions. A response was considered correct if it was consistent with the direction computed by binding the attended color and the high-contrast texture feature across frames. Feedback was given after each trial. Direction accuracy was measured over a range of viewing distances that yielded retinal stimuli varying from 0.5 to 6 c/deg, and d' was computed for each observer and condition. **Results.** Three observers, after initial training, produced similar d' data with cutoff frequencies of approximately 4 c/deg, from which receptive field widths of 12 min were inferred. **Conclusion.** This third-order motion paradigm allows the application of experimental and theoretical tools from psychophysics (linear systems analysis, signal detection theory) to to the cognitive processes of attention.

[1]Z-L Lu & G. Sperling (1995). *Nature,* v377, 237-239.

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MEASURING THE SPATIAL RESOLUTION OF VISUAL ATTENTION

Erik Blaser[1], George Sperling[1], and Zhong-Lin Lu[2]

[1]University of California, Irvine CA 92697, [2]University of Southern California, Los Angeles, CA 90089.

Introduction

Visual attention is defined descriptively as the means by which certain information is given special status when extracted from the visual scene. This special status has been shown psychophysically to result in speeded processing (Posner, Nissen & Ogden 1978) and higher signal to noise ratios (Shaw, 1980; Downing, 1988). Given the influence attention has on the coding of visual information, as well as on subsequent processing, a quantitative understanding of vision must include a quantitative model of attention.

A quantitative model of attention should address three issues: spatial, temporal, and featural resolution. That is, how does the distribution of cued and uncued locations, intervals, and features (in some feature space) affect the magnitude of an attention effect? A full model should also tell us how these variables interact. For instance, if cued and uncued locations are interleaved closely in space, can a resultant loss of spatial resolution be compensated for by increasing the featural distance between areas, say by coloring cued regions red and uncued regions green?

The same theoretical and experimental tools used in psychophysics (linear systems analysis, signal detection theory) can be applied to the study of visual attention (Sperling, 1984). The goal of predicting how well an observer can follow a given attention instruction can be expressed as a goal of predicting how well an observer's attention system can resolve a requested pattern of allocation; and such a prediction can be built up from a knowledge of performance on an appropriate basis set of tasks. Toward this end, we employed a novel methodology for the study of attention. Using the alternating-feature motion stimuli of Lu and Sperling (1996), we quantified the extent to which attention could resolve sinewaves of various spatial frequencies; and in so doing, derived *Attention Modulation Transfer Functions* and *Attention Receptive Fields.*

Alternating-feature stimuli, by design, do not have luminance or texture information of relevance to a motion computation-- in fact, they are invisible to the motion energy analyses associated with the first- (Reichardt, 1957; van Santen & Sperling, 1984; Adelson & Bergen, 1985) and second-order motion systems (Cavanagh & Mather, 1989; Chubb & Sperling, 1989). Instead, the smooth and compelling motion induced by alternating-feature stimuli is perceived by virtue of some area of interest, or *salience*, translating across the display. Fig. 1 shows one of the alternating-feature display types used in this study.

INSERT FIGURE 1 ABOUT HERE

Although the appearance of the bars alternates from frame to frame, the bars are always more salient than the background ('figure' in a figure-ground conceptualization). This type of display, and previous investigation into purely binocular, interocular, and interattribute apparent motion (Petersik, Hicks, & Pantle, 1978; Shadlen & Carney, 1986; Cavanagh, Arguin, & von Grunau, 1989; Zanker, 1993) has lead to proposals of a third motion system (Pantle & Picciano, 1976; Georgeson & Shackleton, 1989; Lu & Sperling, 1995), distinct from the first-order luminance and second-order contrast or texture system. In the third-order motion model presented by Lu and Sperling, motion is extracted from alternating-feature displays by a system that is concerned only with the relative salience of regions of the visual field, abstracting from particular stimulus attributes. Under this scheme, regions are marked on a 'salience map' according to their relative salience, where salience is determined by an interaction of bottom-up biases and top-down influences (Treisman & Gormican, 1988; Kahneman, Treisman & Gibbs, 1992). Following the extraction of salience as a function of space and time, any delay-and-compare motion mechanism, can compute motion between marked regions.

The most remarkable type of alternating-feature displays consist of features of *equal* salience interleaved with frames containing a dominant feature (Fig. 2).

INSERT FIGURE 2 ABOUT HERE

In order to induce motion in these ambiguous displays, the top-down influence of attention is required to raise the relative salience of one of the previously balanced features. *Only when attention renders one feature more salient than its competitor, does such a stimulus give rise to a consistent impression of motion.*

Method

Observers

An experienced observer, EB, and two naive observers, SS and YC, with normal or corrected-to-normal vision served as observers. Observers EB, SS, and YC were run at all spatial frequencies. Naive observers were paid $8.00 per hour for their participation.

Apparatus

All experiments were computer controlled. Stimuli were presented on a NEC JC-1401P38 Multisync color monitor driven by an Altec 386 IBM compatible computer. Images were generated off-line using the HIPS image processing software (Landy, Cohen & Sperling, 1984), and displayed using the Runtime Library for Psychology Experiments (1988) driving an AT-Vista video graphics adapter. Only the red and green guns of the monitor were used. Responses were entered by observers via keyboard and all observers used a chin rest to control for viewing distance and to stabilize head movements. Trials were run in an otherwise dark room.

Construction of stimuli

The stimuli were motion displays consisting of a temporal sequence of five spatially coincident frames, each of which contained a horizontal sinewave grating. The gratings occurred inside a rectangular aperture 10.7 cm wide and 6.6 cm tall. Temporal frequency was 2.5 Hz, object frequency was 4 cycles, and spatial frequency was 0.50 c/deg at a viewing distance of 0.75 meters.

Motion frames contained one of two types of gratings, an isoluminant red/green grating, or a contrast modulated noise grating. To create the red/green grating, the monitor's red gun output was modulated sinusoidally from 0 to 0.15 w/sr/m2 in space, while a sinusoidal modulation of the green gun from 0 to 0.075 w/sr/m^2 was superimposed in counterphase. The compound grating appeared as a spatial modulation between red and green, through background orangy-gold (Fig. 3a). Pilot

experiments indicated that a grating of this type is of balanced salience. That is, observers did not have a significant bias to regard one of the colors as 'figure' and the other as 'ground'.

The modulated noise grating was constructed by sinusoidally varying the contrast of a binary noise patch. Since pixels of opposite polarity in a given column of pixels were deviated symmetrically from background (using a linearized look-up table), the grating was isoluminant. This grating appeared as a modulation between background orangy-gold and a high contrast black and bright gold noise texture (Fig. 3b). Pilot experiments established that the regions of high-contrast texture in a grating of this type are perceived as figure.

INSERT FIGURE 3 ABOUT HERE

The background in which both types of frames matched the point at which the red and green sinewaves of the red/green grating crossed.

Three types of motion displays were constructed from these red/green and modulated noise frames: *Top-down*, *Bottom-up*, and *No-motion*. *Top-down* displays were constructed by alternating between red/green and modulated noise frames, with each frame displaced 90 degrees consistently to the right or left relative to its predecessor, which is ideal for motion detection (van Santen & Sperling, 1985). Objectively, if the red areas of the red/green gratings and the high contrast areas of the modulated noise gratings are tracked across frames, motion is defined in one direction, while if green areas are bound to high contrast areas, motion is defined in the opposite direction. Initially, such displays appeared noisy and ambiguous to observers. However, given the instruction to attend to one of the colors in the red/green grating, a clear impression of motion emerged after a few hundred trials of practice.

Bottom-up displays were identical to the Top-down displays except that the unattended color in the red/green grating was reduced in saturation (moved closer to background). The unattended color was either reduced in saturation by 80% (observers SS and EB), or extinguished altogether (observer YC). By physically manipulating the competing features in this way, relative salience can be changed a priori. Observers SS and EB found the more saturated color to be of higher salience, and were biased to regard this feature as figure; observer YC could not help but regard the appropriate color bars as figure, since they were the only

bars in the display. This manipulation of the stimulus was designed to physically mimic the effect of attention instructions. In these displays, observers did not have to explicitly attend to any particular feature, since the saturation adjustments influenced salience in a bottom-up fashion. Since our saturation adjustments were large, and induced an inescapable bias to perceive motion in the direction consistent with the feature of greatest saturation, we expected these displays to put an upper bound on performance.

No-motion displays were constructed by simply repeating the first two frames of a Top-down display (Fig. 4). This produced a stimulus for which it is impossible to define a direction of motion.

INSERT FIGURE 4 ABOUT HERE

These trials sought to determine if observers resorted to alternate strategies to generate responses given the absence of a motion signal.

Procedure

It was preferable that the red and green features used be nearly isoluminant, thereby reducing any difference in salience, and any first-order motion noise. Red-green isoluminance was found for observer SS via a minimum boundary technique (Wagner & Boynton, 1972), whereas stimuli for observers EB and YC were calibrated via a minimum motion technique (Anstis & Cavanagh, 1983). Such calibrations were done for every viewing distance. Any luminance contamination would reveal itself as a systematic bias in observers' data to see motion consistent with a particular color. The near symmetry of 'attend red' and 'attend green' performance argues against such contamination.

An individual trial consisted of a 500 msec blank frame containing a fixation point, followed by a five frame motion display (5 frames @ 100 msec each), followed by another fixation frame (Fig. 5). Following this sequence, observers were required to enter a direction of motion judgment.

INSERT FIGURE 5 ABOUT HERE

A beep indicated a correct response, while random feedback was given for responses to No-motion trials. The next trial began immediately following feedback. Starting frame type (red/green or modulated noise), starting phase (0, 90, 180, or 270 degrees), and 'direction' (+/- 90 deg phase shift) were randomized from trial to trial.

Before each block of trials, observers were given one of two instructions: "Give your full attention to the *red* regions of the stimulus" or "Give your full attention to the *green* regions of the stimulus." Observers were always instructed to indicate the global motion of the display with their response. A response was considered correct if it was consistent with the direction of motion indicated by tracking attended regions and the high contrast regions across frames. Naive observers SS and YC were run in mixed blocks of all three display types (Top-down, Bottom-up, and No-motion), mixed in proportions of 3/5, 1/5, and 1/5, respectively. These observers were not aware of the presence of the No-motion trials. Observer EB was run in mixed blocks of only Top-down and Bottom-up displays (mixed in proportions of 4/5 and 1/5, respectively). Observers SS and EB were run in blocks of 240 trials, while observer SS was run in blocks of 160 trials.

Five viewing distances (0.75, 1.5, 2.5, 6.0, and 9.0 meters) were used to achieve spatial frequencies of 0.50, 1.0, 1.6, 4.0, and 6.0 c/deg. The sequence of conditions was as follows. Initially, performance was measured under 'attend red' instructions at 0.50 c/deg. Then 'attend green' performance was measured at the same spatial frequency. Following this, observers were run at 1.0 c/deg under the same attention instructions. This sequence progressed until the observer had run with both attention instructions at all viewing distances.

Results

Significant learning effects were evident, and we attempted, within the time constraints of the experiment, to measure asymptotic performance. Performance under 'attend red' and 'attend green' instructions was approximately symmetric, therefore averaged data were analyzed. Performance was plotted as motion direction sensitivity (in units of d') versus spatial frequency. Attention Modulation Transfer Functions were calculated by fitting a polynomial to these data points. To determine corresponding Attention Receptive Fields, the AMTF's were sampled to yield the amplitude of cosine functions, which were aligned and summed. This amounts to a discrete inverse Fourier transform of

these data (Anderson & Burr, 1989).

Approximate AMTF cutoff frequencies were taken as those corresponding to a d' of 1.0 . Observer EB had a Top-down cutoff frequency of 4 c/deg and a Bottom-up cutoff of 5 c/deg (Fig. 6). Observer SS had a Top-down cutoff frequency of 4 c/deg and a Bottom-up cutoff of 5 c/deg (Fig. 7). Finally, observer YC had a Top-down cutoff frequency of 3 c/deg and a Bottom-up cutoff of 4 c/deg (Fig. 8). As expected, Bottom-up motion performance was in superior to that of Top-down motion.

INSERT FIGURES 6, 7, and 8 ABOUT HERE

The inferred receptive field for observer EB had a full width at half height of approximately 12 min of visual angle for both Top-down and Bottom-up conditions (Fig. 9). The ARF's for observer SS (Fig. 10) and YC (Fig. 11) also had widths of 10-12 min.

INSERT FIGURES 9, 10, and 11 ABOUT HERE

Conclusions

In attention paradigms, observers are instructed to attend to particular regions, intervals, and/or features of the visual scene while performing some task. Along these dimensions, there are countless patterns of allocation that an experimenter could ask of an observer, and some of these instructions are more easily followed than others. A general, predictive model can be approached as a problem of determining the spatial, temporal, and featural *resolution* of attention.

We developed a methodology, using the third-order alternating-feature stimuli of Lu and Sperling, tailored to linear systems analysis. This methodology was applied in the space domain to measure Attention Modulation Transfer Functions and Attention Receptive Fields. Three observers, after initial training, produced similar d' data with cutoff frequencies of approximately 4-5 c/deg, from which receptive field widths of 10-12 min were inferred.

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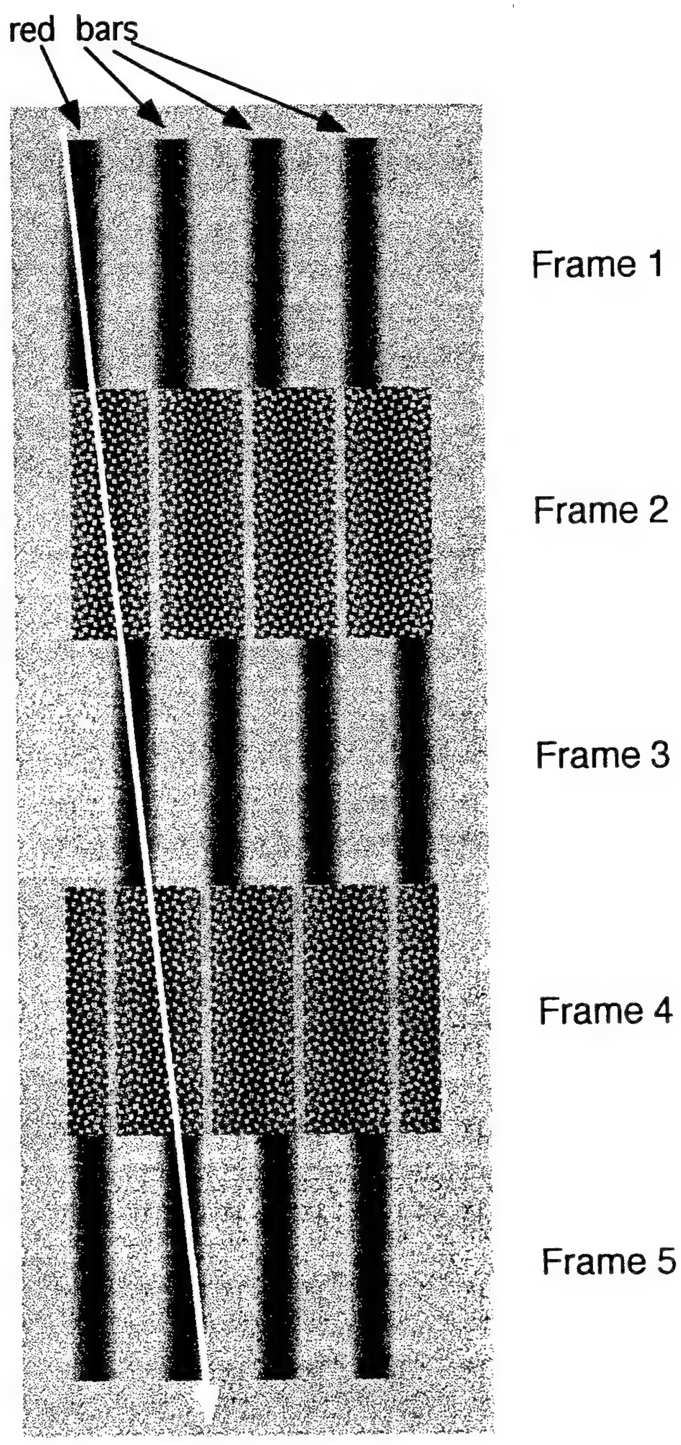

Figure 1. 'Bottom-up' alternating-feature display. Red areas and high contrast areas are the most salient features, and are automatically perceived as 'figure'. Motion is defined with respect to these salient regions. The perceived direction of motion is indicated by the large arrow.

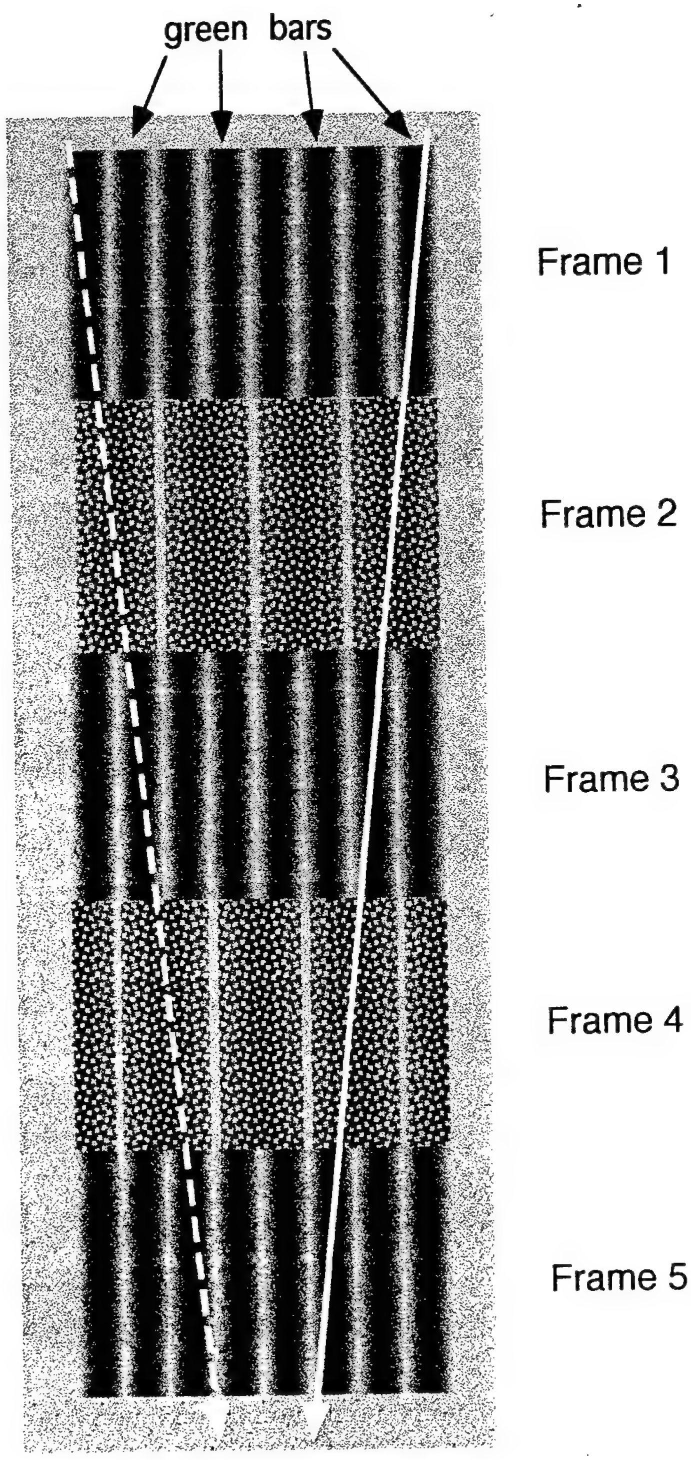

Figure 2. 'Top-down' alternating feature display. Red areas and green areas are of equal salience and there is no significant bottom-up bias to regard one color as figure and the other ground. The high constrast features are automatically perceived as figure. The perceived direction of motion is contingent upon attentional state. If attention is on the red regions, their relative salience is increased and they are marked as figure. Motion is then perceived in the direction indicated by the solid arrow. On the other hand, attention to the green regions results in the perception of motion in the oppposite direction as indicated by the dotted arrow.

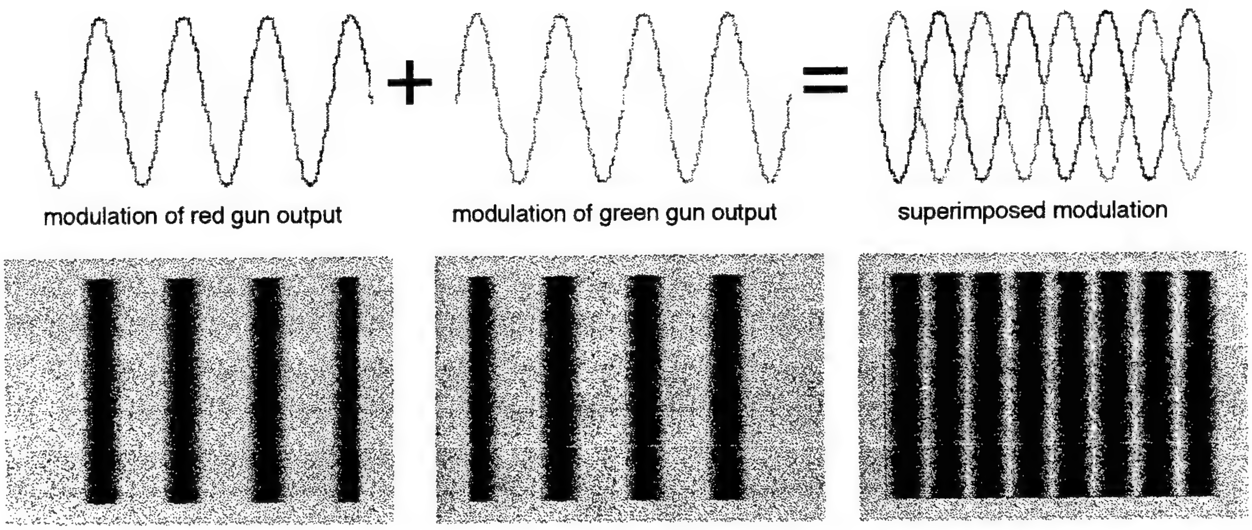

Figure 3a. Red/green gratings are constructed by superimposing, in counterphase, a sinewave modulation of the monitor's red gun with a modulation of the green gun. Calibration procedures ensure that the compound grating is near isoluminant. Background is set to the crossing point of the two gratings.

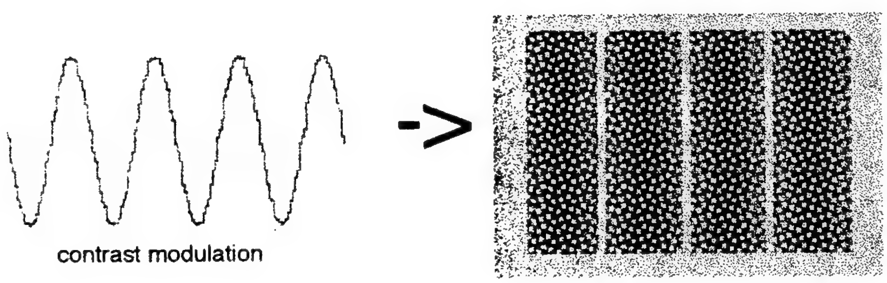

Figure 3b. Contrast gratings are constructed by a sinewave modulation of the contrast of a binary noise patch. Such a grating is isoluminant when viewed from afar. Background is identical to the red/green grating.

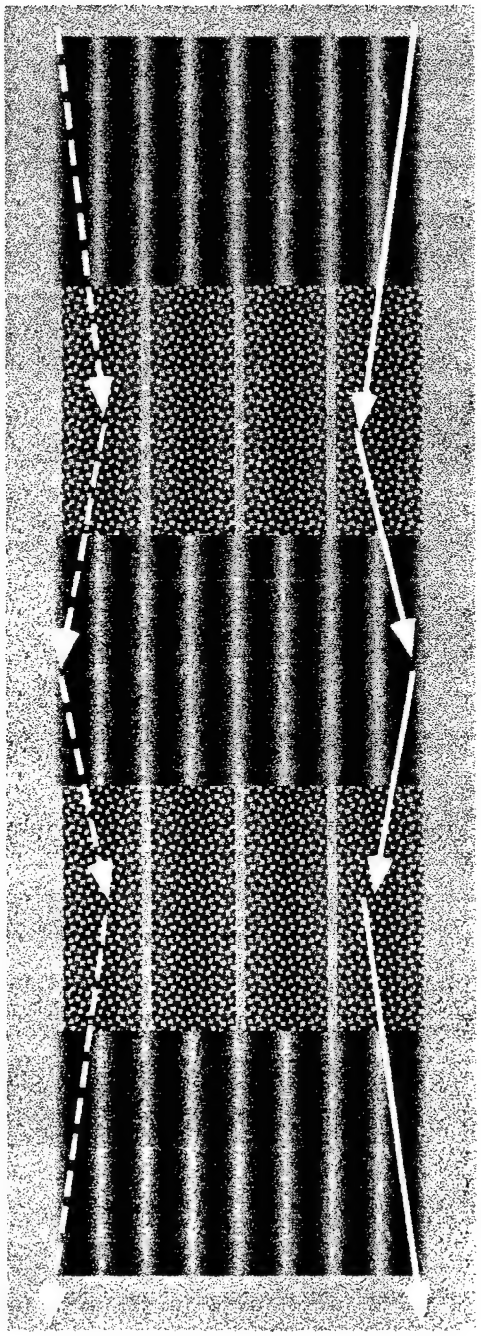

Figure 4. 'No-motion' display. Note that a consistent direction of motion cannot be defined. Attend-red zig-zag path is indicated by a dotted arrow, and attend-green zig-zag path is indicated by a solid arrow.

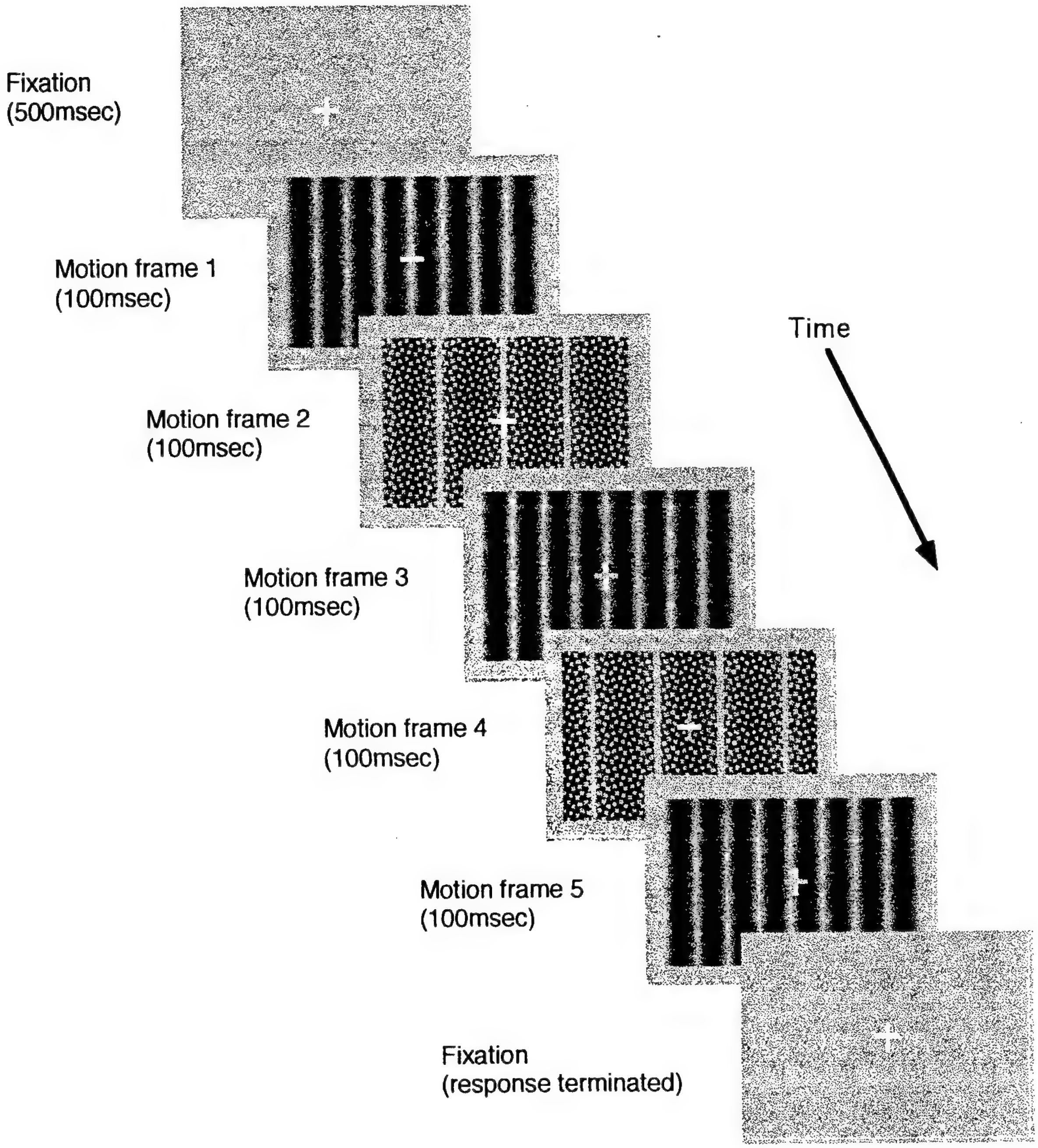

Figure 5. All trials consist of a 500 msec fixation frame, a five frame motion sequence, and a response terminated fixation frame.

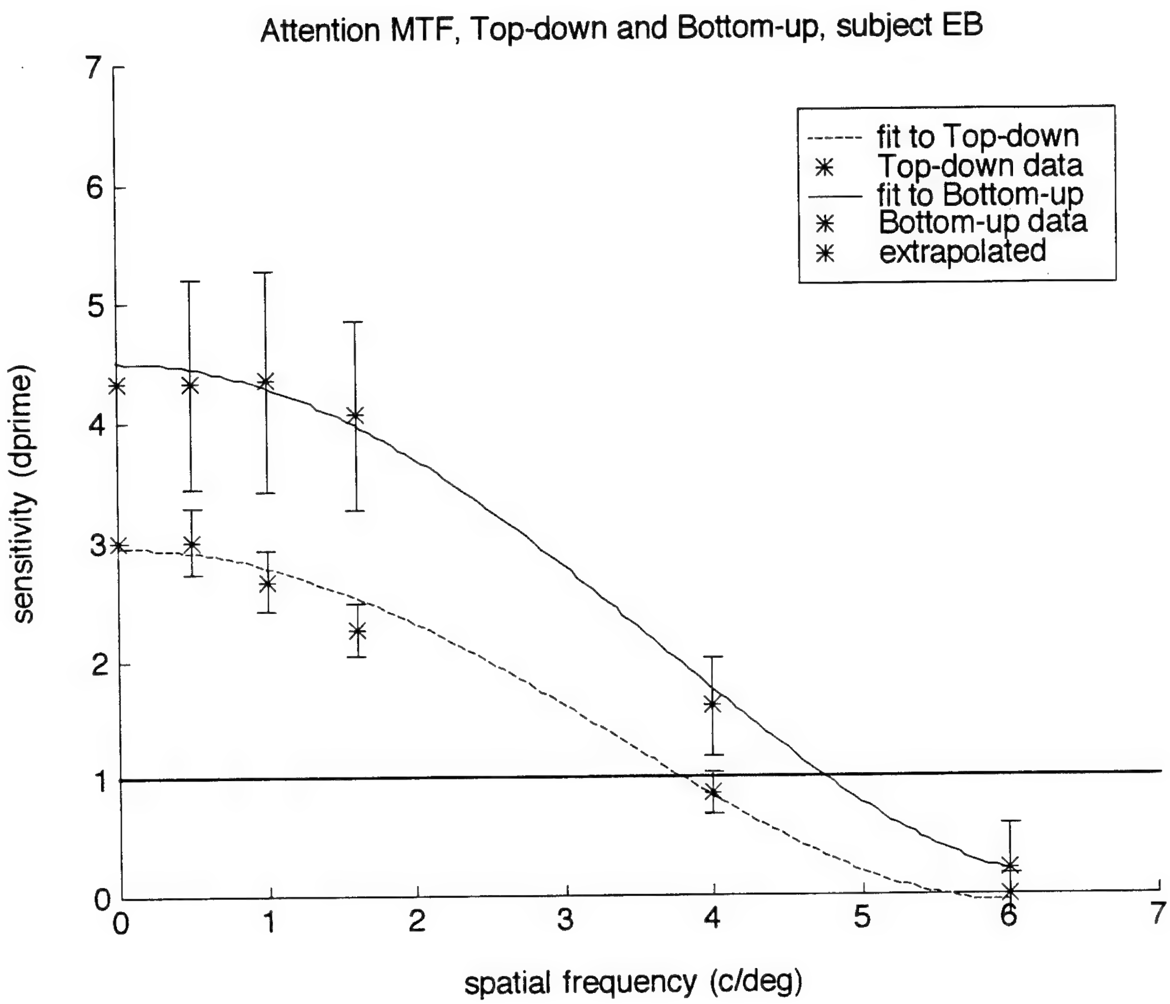

Figure 6. Attention Modulation Transfer Function for subject EB. Sensitivity is plotted vs. spatial frequency, with 95% confidence intervals shown. The smooth curve is a theoretical AMTF generated by a polynomial fit. This curve is sampled to provide the amplitude spectrum of cosine components which are aligned and summed to generate receptive field profiles. Cutoff frequencies are those associated with a d' of 1.0; this is indicated by the solid line. Cutoff frequencies were approximately 4 c/deg for the Top-down condition and 5 c/d for the Bottom-up condition.

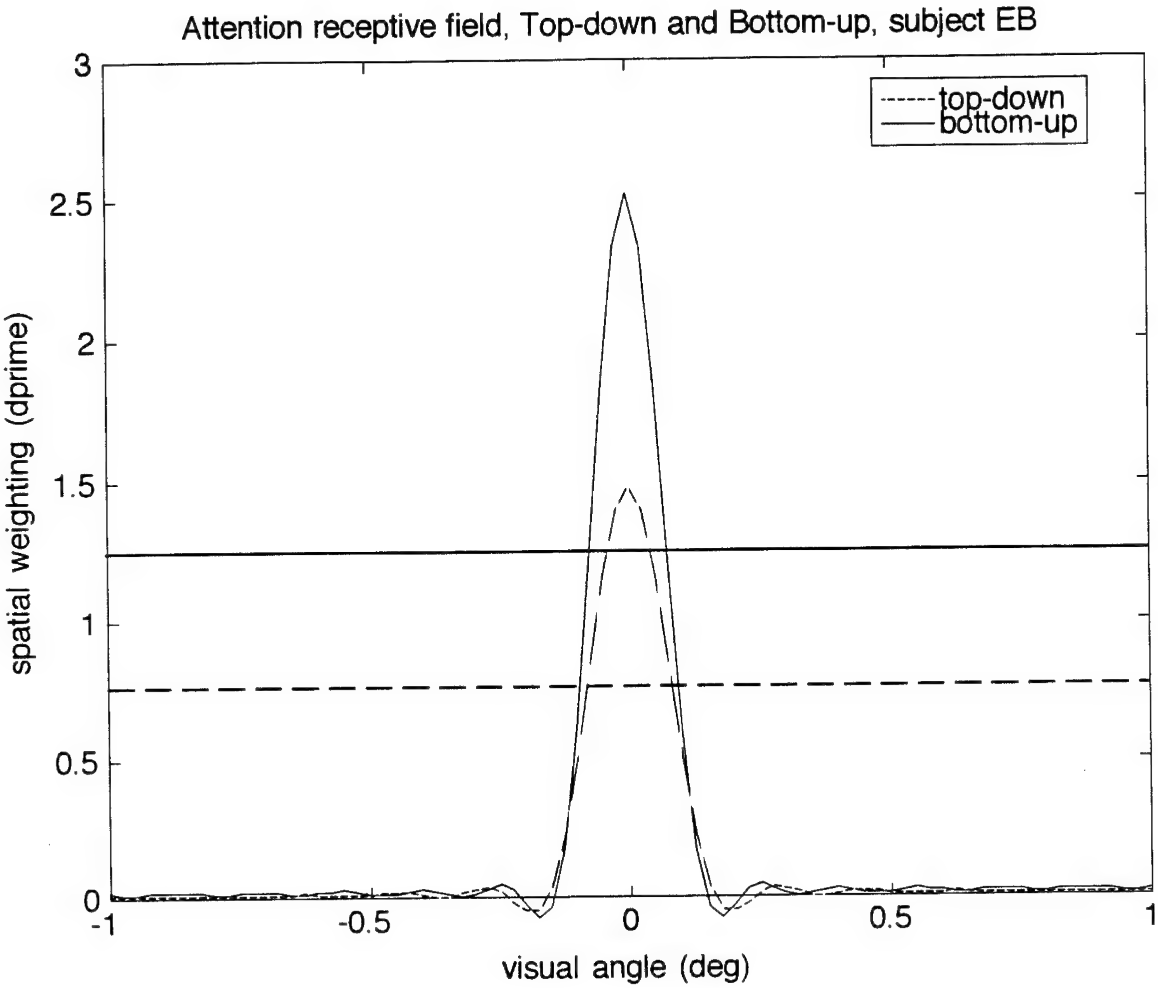

Figure 7. Attention Receptive Fields for subject EB. Sensitivity is plotted vs. visual angle. The receptive field profile is generated by sampling the AMTF to provide the amplitude spectrum of cosine components which are aligned and summed. The half-height for the Top-down condition is indicated by the dashed line and half-height for the Bottom-up condition is indicated by the solid line. Widths at these heights, for both conditions, are approximately 10-12 min of visual angle.

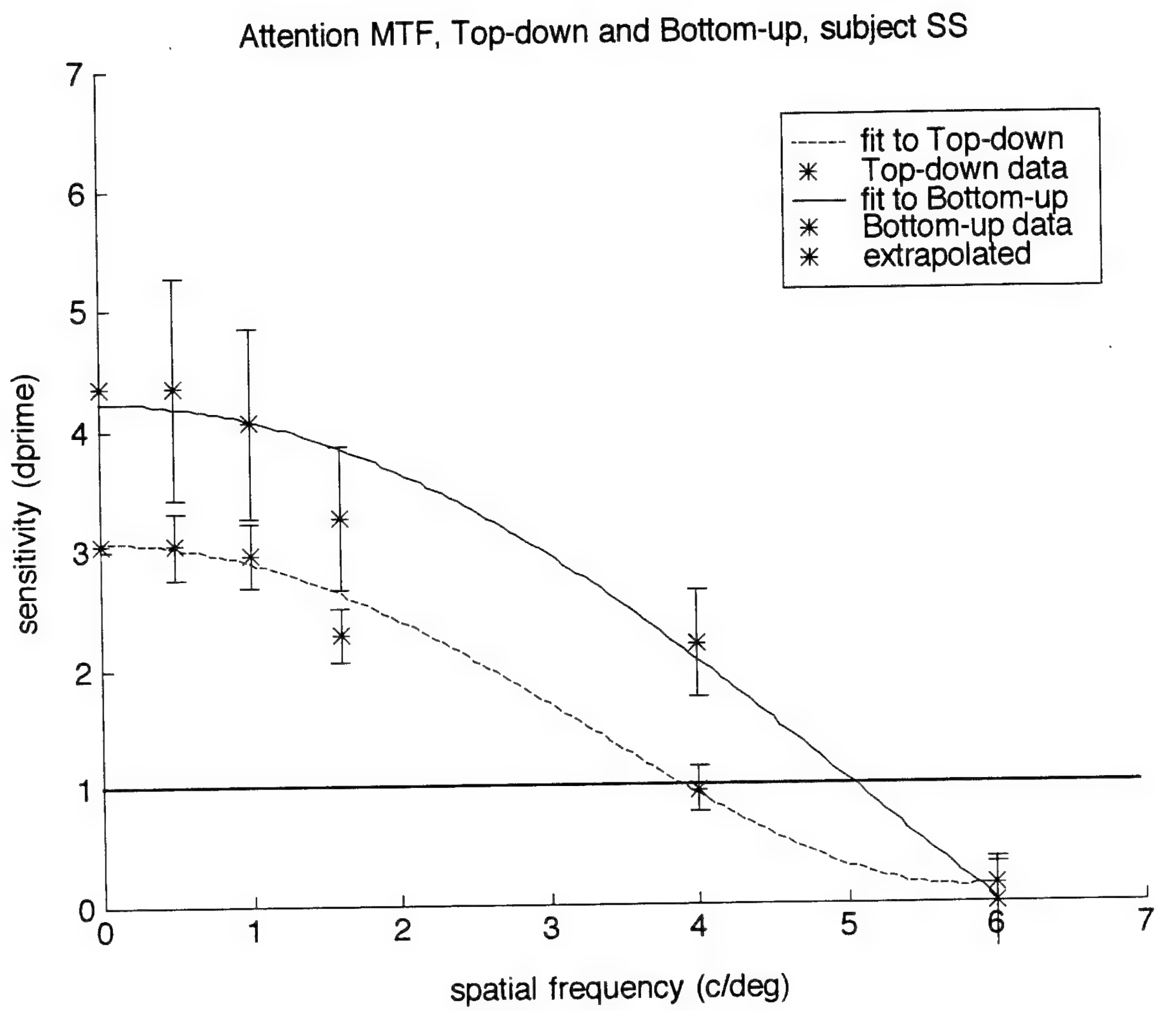

Figure 8. Attention Modulation Transfer Function for subject SS. Sensitivity is plotted vs. spatial frequency, with 95% confidence intervals shown. The smooth curve is a theoretical AMTF generated by a polynomial fit. This curve is sampled to provide the amplitude spectrum of cosine components which are aligned and summed to generate receptive field profiles. Cutoff frequencies are those associated with a d' of 1.0; this is indicated by the solid line. Cutoff frequencies were approximately 4 c/deg for the Top-down condition and 5 c/d for the Bottom-up condition.

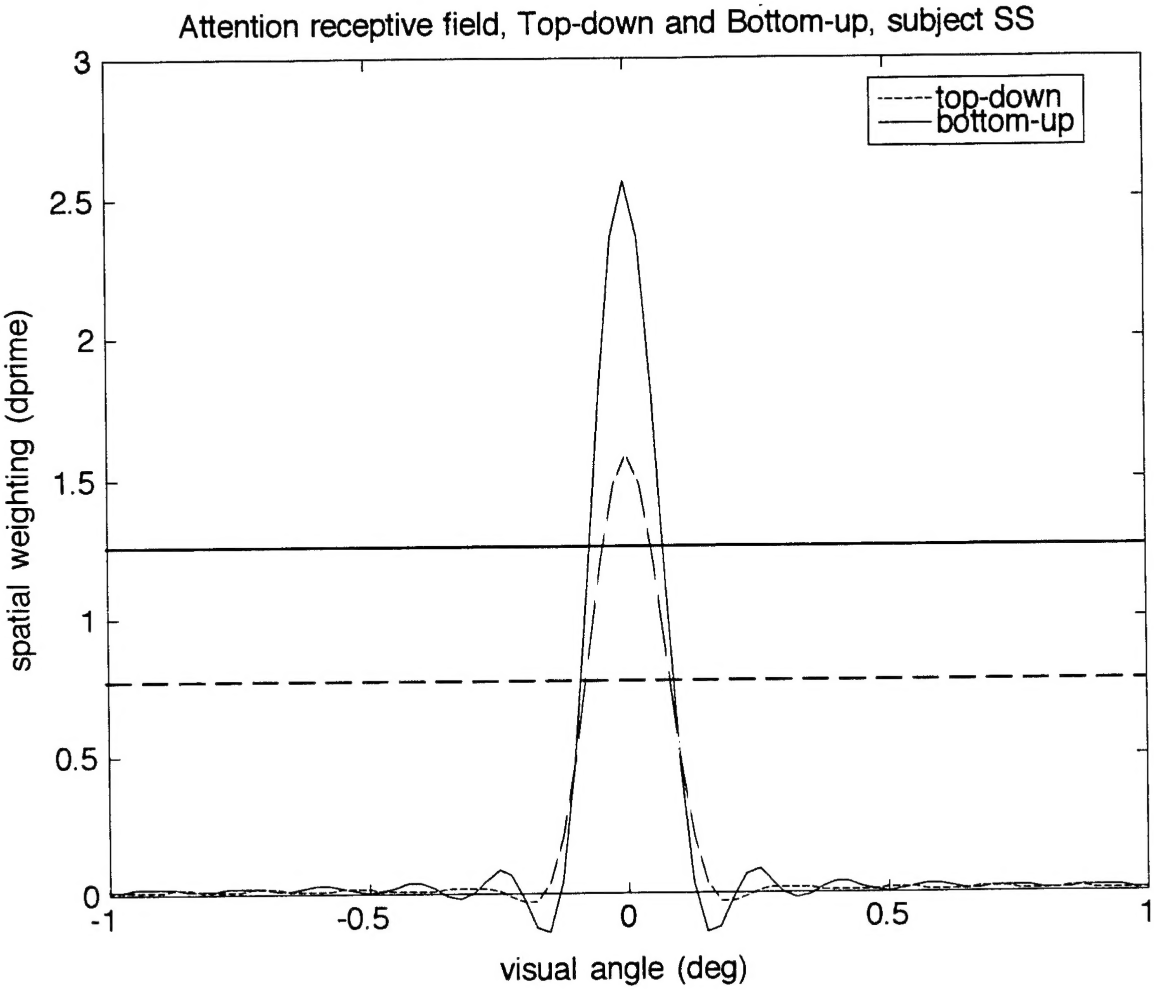

Figure 9. Attention Receptive Fields for subject SS. Sensitivity is plotted vs. visual angle. The receptive field profile is generated by sampling the AMTF to provide the amplitude spectrum of cosine components which are aligned and summed. The half-height for the Top-down condition is indicated by the dashed line and half-height for the Bottom-up condition is indicated by the solid line. Widths at these heights, for both conditions, are approximately 10-12 min of visual angle.

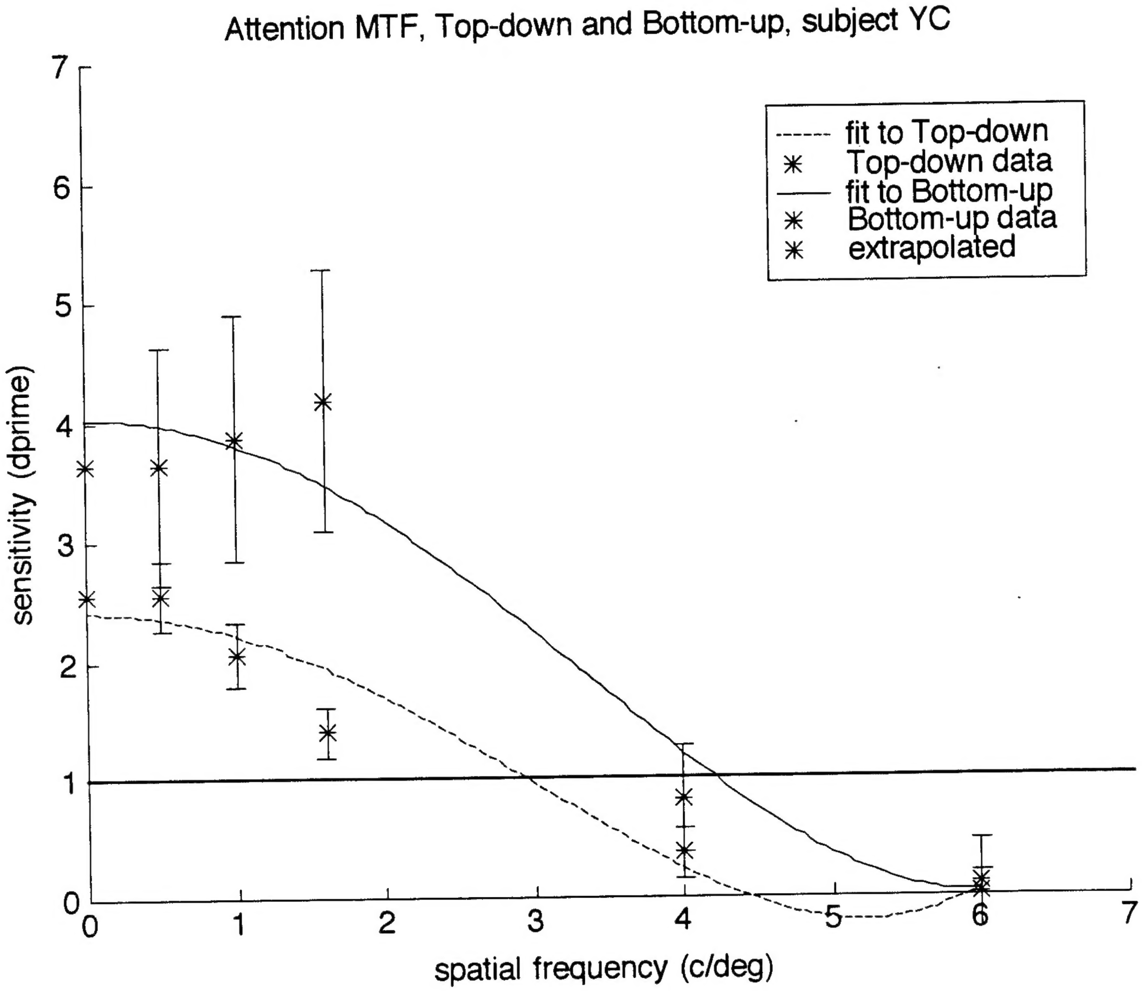

Figure 10. Attention Modulation Transfer Function for subject YC. Sensitivity is plotted vs. spatial frequency, with 95% confidence intervals shown. The smooth curve is a theoretical AMTF generated by a polynomial fit. This curve is sampled to provide the amplitude spectrum of cosine components which are aligned and summed to generate receptive field profiles. Cutoff frequencies are those associated with a d' of 1.0; this is indicated by the solid line. Cutoff frequencies were approximately 3 c/deg for the Top-down condition and 4 c/d for the Bottom-up condition.

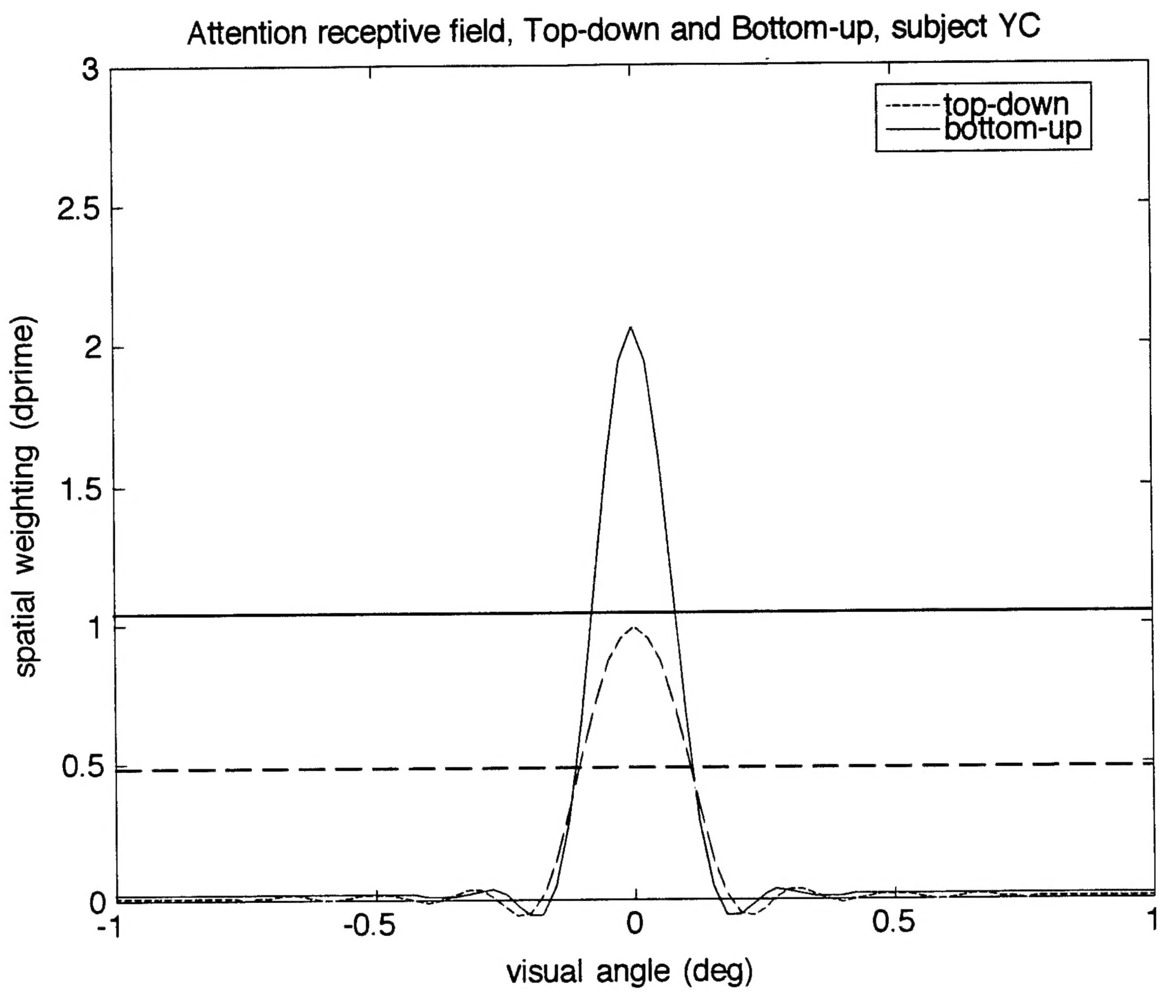

Figure 11. Attention Receptive Fields for subject YC. Sensitivity is plotted vs. visual angle. The receptive field profile is generated by sampling the AMTF to provide the amplitude spectrum of cosine components which are aligned and summed. The half-height for the Top-down condition is indicated by the dashed line and half-height for the Bottom-up condition is indicated by the solid line. Widths at these heights, for both conditions, are approximately 10-12 min of visual angle.

*** DTIC DATA ***

P. R. NUMBER:	FQ8671-9301570
PROPOSAL NUMBER:	93NL173
TYPE SUBMISSION:	FINAL DOC# 3173e, pg. 13
INST. CONTROL NUMBER:	F49620-93-1-0520
INSTITUTION:	Univ of California, Irvine
P.I. NAME:	Dr George Sperling
INVENTION IND:	NONE
PROJECT/TASK:	3484 YS
PROGRAM MANAGER:	DR. JOHN TANGNEY

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3. Progress:

@38@UNARR. ------ PROG. - FROM 01 Sep 93 TO 31 Aug 96

This grant was used to support the graduate education of Erik Blaser, who is currently in his fifth year of graduate study for a Ph.D. degree in the Department of Cognitive Science, University of California, Irvine. Blaser's formal course work proceeded normally throughout with very high grades (A or Satisfactory in all his courses). Blaser failed to finish in a par four years, and is now in his fifth year, currently supported as a teaching assistant, and concentrating fully on completing his thesis research. His thesis project is a method of measuring the modulation transfer function of spatial visual attention. When the assumptions of his method of measuring attention are satisfied, the method enables one to calculate, for any attentional demand whatsoever, the extent to which an observer could mould his or her distribution of spatial attention to meet the demand. This research is being reported at ARVO, 1997, and a preliminary report is attached herewith.